

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION

for

**ELECTRIC MOTOR STATOR CURRENT CONTROLLER**

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## **Electric Motor Stator Current Controller**

### **Technical Field**

The present invention relates to electric motors and, more particularly, to circuits that  
5 control stator currents within electric motors.

### **Background Art**

To achieve desired motor movement, the phase of currents flowing through motor windings must be synchronized. In DC motors employing rotor magnets, currents of the  
10 stator windings must be phased properly so that the angular position of the magnetic field generated by the stator currents has the proper orientation with respect to the magnetic fields associated with the rotor magnets. Key to proper phasing is knowledge of the angular position of the rotor and its magnets relative to that of the stator. In DC motors with commutators (i.e., brushes), proper phasing is done automatically. In contrast, brushless DC  
15 motors require detectors to detect changes in the magnetic fields associated with changes in the angular position of the rotors.

Magnetic field detectors often incorporate a Hall effect device mounted on a printed circuit board. Orientation of the Hall effect device is important because the device is most sensitive to magnetic fields perpendicular to one pair of its surfaces. To that end, many  
20 motors mount a Hall effect device on a printed circuit board that is perpendicular to the rotor axis. To be properly oriented to sense the magnetic field generated by the rotor magnets, the Hall effect device is mounted on its edge perpendicular to the circuit board, usually occupying a region between the rotor magnets and the stator so as to permit the device to detect the magnetic fields produced by the rotor magnets.

25 Surface mounting circuitry produces significant cost advantages in terms of speed of assembly. However, surface mounting the Hall effect device on a circuit board located perpendicular to the rotor axis both 1) removes the device from the region of maximum magnetic field and 2) orients the device in a manner that is least sensitive to the magnetic

fields generated by the rotor magnets. In other words, mounting a Hall effect device in this manner does not permit its surfaces to be perpendicular to the magnetic field, thus minimizing its functionality.

### **Summary of the Invention**

5           In accordance with one aspect of the invention, a stator current controller is provided within an electric motor having a stator, a rotor with a rotor magnet, and an arbor for securing the rotor to the stator. The rotor has an inner surface defining a bounded region. A circuit board containing a magnetic field detector for detecting a magnetic field produced by the rotor magnet is coupled to the arbor and lies, at least in part, within the bounded region.

10           In accordance with a further aspect of the invention, the magnetic field detector may be positioned closer to the bottom end of the arbor than to the top end. The circuit board may be snapped onto the arbor and may be oriented not to be perpendicular to an arbor axis.

          In accordance with a still further aspect of the invention, the magnetic field detector may be contained in a chip surface mounted onto the circuit board and may include a Hall  
15 effect device. Electrical connections to the printed circuit board may include connections to a voltage supply, to ground, and to a plurality of stator windings.

          In accordance with still another aspect of the invention, a motor may incorporate the magnetic field detector. The motor may be a brushless DC motor.

### **Brief Description of the Drawings**

20           The foregoing features of the invention will be more readily understood by reference to the following detailed description, taken with reference to the accompanying drawings, in which:

          Fig. 1 shows an electric fan that may include a magnetic field detector in accordance with illustrative embodiments of the invention.

25           Fig. 2A and Fig. 2B are schematic vertical and horizontal cross-sectional views of the fan of Fig 1.

          Fig. 3 is a functional diagram of illustrative magnetic field detection circuitry and current driving circuitry that may be within the fan shown in Fig. 1.

### **Detailed Description of Specific Embodiments**

Because of their economy and performance, DC electric motors are used in a variety of appliances, such as fans. Control of the applied DC voltage permits a wide variation in speed and torque in a compact package. The magnetic fields generated by currents flowing through the windings of the stationary stator interact with magnetic fields generated by magnets on the rotating rotor to create rotor torque.

Proper rotor rotation requires that the stator magnetic field have a spatial relationship with the rotor magnetic field. Temporal sequencing of the electrical currents flowing through the stator windings specifies this relationship. Previously, switching was done by mechanical commutation. As the rotor turned, different windings were energized. More recent brushless DC motors avoid problems of mechanical wear and variation of brushes by electronically switching the currents flowing through the stator windings. Proper switching, however, requires an accurate position of the rotor relative to the stator.

Rotor position may be sensed by means of a Hall effect device positioned to detect rotor magnetic fields. Maximum sensitivity may be achieved by measuring the magnetic field at a location where the rotor magnetic field is greatest. Maximum accuracy may be achieved by ensuring that the magnetic field exhibits little spatial variation at the measurement location. Although the magnetic field sensor may be positioned underneath the edge of the rotor, reliance on small fringing fields may require accurate placement of the sensor very close to the rotating magnets. In illustrative embodiments discussed below, the Hall effect device is located within the cylinder formed by the inner surface of the rotor magnets. The Hall effect device thus measures the radial magnetic field generated by the rotor magnets. It is preferable to measure the radial magnetic field because, unlike the fringing magnetic fields, the radial magnetic field is substantial and relatively uniform.

The location of the Hall effect device within the rotor radial magnetic field constrains its mounting on a printed circuit board that also carries associated electronics. For an edge mounted Hall effect device, the board may be mounted horizontally beneath the rotor. However, for a Hall effect device surface mounted on such a board, as is advantageous from an assembly point of view, the limited elevation of the device above the board does not allow the device to interact with the radial magnetic fields. Rather, the Hall effect device only interacts with the less substantial fringing magnetic fields. To overcome this problem,

aspects of the invention permit detection of rotor position through measurement of radial magnetic fields with a surface mounted Hall effect device. Details are discussed below.

Fig. 1 illustrates a cooling fan embodiment of a DC electric motor having an illustrative stator current controller that incorporates a magnetic field detector. A cooling fan  
5 **100** contains a rotor **110** mounted within a venturi housing **120**. As the rotor **110** revolves, fins **115** attached to the rotor **110** cause air to flow through the housing **120**. The fan **100** operates in a conventional manner, such as that described in U.S. Patent 4,656,553, hereby incorporated in its entirety by reference to the extent that it is consistent with embodiments of this invention.

10 Fig. 2A and Fig. 2B schematically show vertical and horizontal cross-sectional views, respectively, of the cooling fan embodiment of Fig. 1. The fan **100** has a stator **210** that together with an arbor **220** forms an arbor-stator assembly **230**. The stator **210** contains poles **213** and interpoles **214**. The poles **213** carry windings **212** so connected that the magnetic field produced by current through the windings **212** reverses direction from one  
15 pole to an adjacent pole. The interpoles **214** positioned between adjacent poles **213** carry no current. In other embodiments, stators may be used that do not incorporate interpoles.

The rotor **110** is rotationally connected to the arbor-stator assembly **230** by conventional means, such as by a shaft **211** and by a pair of bearings **235**. The rotor **110** also has a plurality of rotor magnets **215** that may contain a field section **216** and a commutating  
20 section **217**. Since this embodiment contains a four pole motor, the direction of magnetization through the thickness of the commutating section **217** reverses direction every 90°. A rim **212** comprised of a highly permeable material such as steel surrounds an outer surface **209** of the magnets **215**, thereby providing a return path for the magnetic flux. The rotor magnets **215** extend axially beyond a top **226** of the stator **210**, tending to maintain the  
25 seating of the rotor shaft **211** within the bearings **235**.

The rotor magnets **215** are spaced from, but circumscribed about, the outer surface **225** of the stator **210**. The rotor magnets **215** have an inner rotor surface **218** that is considered to form a bounded region **219**. This bounded region **219** effectively is a substantially cylindrical region bounded by the inner rotor surface **218** (i.e., by the rotor  
30 magnets **215**, and, in some embodiments, by the commutating section **217** of the rotor

magnets **215**). In illustrative embodiments, the axis **294** of the arbor **220** coincides with the respective axes **292** and **296** of the rotor **110** and the bounded region **219**.

In accordance with illustrative embodiments, a printed circuit board **240** having stator control circuitry mounts directly onto the arbor **220**. Among other ways, the board **240** may  
5 be mounted at least in part by arbor snaps **235**. Inputs to the printed circuit board **240** may be a supply voltage **270** and a ground **271**. Outputs from the printed circuit board **240** may be connections to the stator windings **275** and **276** and a fault or tachometer signal **272**. The printed circuit board **240** also has a surface mounted chip **250** containing a stator current  
10 controller circuitry **252** that further may contain a magnetic field detection circuitry **254** and a current driving circuitry **256**. The magnetic field detection circuitry **254** may further contain a Hall effect device **255**. One embodiment of such a surface mounted chip **250** is the Melexis S72/73.

To assure proper commutation, the board **240** is mounted to the arbor **220** so that Hall effect device **255** is within the bounded region **219**. Moreover, to further ensure detection of  
15 rotor magnetic fields, the board **240** is illustratively located closer to the arbor bottom **224** than to the arbor top **222**. In addition, to effect rotor rotation in a particular direction, the Hall effect device **255** may be displaced to one side of the position of symmetry between adjacent poles **215**, i.e., to one side of the center of an intervening interpole **214**.

Fig. 2B schematically illustrates the embodiment of Fig. 1 in horizontal cross-section.  
20 Stator windings **212** surround each stator pole **214** and control the size and orientation of the magnetic fields generated by the stator **210**. Rotor rotation results from the interaction between fields generated by the magnets **215** and electrical currents through the stator windings **212**. Magnets **215** are magnetized perpendicular to the inner rotor surfaces **218** and generate a magnetic field largely radial in direction within the bounded region **219**. The  
25 stator **210** also generates a radial magnetic field as a result of current flowing through the stator windings **212** surrounding the stator poles **214**. Current through stator windings **212** is sequentially reversed by stator current driving circuitry **256**, based on the position of magnetic field of the rotor magnets **215** as detected by the Hall effect device **255**. This sequential reversal of current through the stator windings **212** produces a torque on the rotor  
30 **110** of proper size and direction.

Fig. 3 shows a functional schematic diagram of an embodiment of the printed circuit board **240** containing the voltage supply input connection **270**, the ground input connection **271**, the stator winding output connections **275** and **276**, the fault or tachometer output connection **272**, and the surface mounted chip **250**. The surface mounted chip **250** contains a diode **510**, a capacitor **520**, and the stator current controller circuitry **252**. The stator current controller circuitry **252** contains the magnetic field detection circuitry **254** and the current driving circuitry **256**. The magnetic field detection circuitry **254** contains the Hall effect device **255** located at X and the current driving circuitry **256** contains a driver **530** and a driver **535** with outputs **275** and **276** respectively connected to the stator winding **212**. The magnetic field detection circuitry **254** generates a voltage V indicative of the magnetic field in which the Hall effect device **255** is immersed. The amplifiers **530** and **535** receive voltage V as input and furnish as output a current I that passes through stator coil **212**. This circuit is exemplary, however, and thus not intended to limit the scope of the invention.

In alternative embodiments, the above discussed functionality on the printed circuit board **240** is split between two or more areas in the motor. In such embodiments, however, the Hall effect device **255** still is positioned as discussed above.

The described embodiments of the invention are intended to be merely exemplary and numerous variations and modifications will be apparent to those skilled in the art. All such variations and modifications are intended to be within the scope of the present invention as defined in the appended claims.